

# HARBOR SEAL POPULATION TRENDS AND FACTORS INFLUENCING COUNTS ON TUGIDAK ISLAND, ALASKA

Lauri A. Jemison and Grey W. Pendleton

Alaska Department of Fish and Game  
P.O. Box 240020  
Douglas, Alaska 99824  
lauri\_jemison@fishgame.state.ak.us

## INTRODUCTION

Population trends of harbor seals (*Phoca vitulina richardsi*) in Alaska vary regionally. In southern and north central Southeast Alaska, populations have been stable or increasing since the early 1980s (Small *et al.* 2001). Harbor seal numbers in Glacier Bay (northern Southeast Alaska), declined 25 – 48% from 1992 – 1998 (Mathews and Pendleton 2000), and counts of seals at terrestrial sites in Prince William Sound have declined 63% from 1984 – 1997 (Frost *et al.* 1999). Data from Nanvak Bay, in northern Bristol Bay, indicate that seal numbers were considerably lower in the early 1990s than in 1975 (Jemison *et al.* 2001).

The first evidence of a decline in harbor seals in Alaska was documented at Tugidak Island, 40 kilometers southwest of Kodiak Island in the western Gulf of Alaska. Based on biennial counts conducted from 1976 - 1988, harbor seal abundance declined 72% - 85% (Pitcher 1990). Tugidak Island was perhaps the largest harbor seal haulout in the world during the 1950s and 1960s, when an estimated 15,000 - 20,000 seals came ashore (Mathisen and Lopp 1963, Pitcher 1990). Commercial harvests from the early 1960s through 1972 removed an estimated 18,000 seals from the island, about 90% of which were pups. The harvests likely were responsible for a decline in the number of seals during and after the harvest period, however a simulation model of the effects of the harvest suggested that the population should have stabilized by the mid 1970s followed by a slow increase (Pitcher 1990). During the past 30 years, population declines also have occurred in Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), and several species of piscivorous seabirds in the Gulf of Alaska and the Bering Sea (Braham *et al.* 1980, Fowler 1982, Merrick *et al.* 1987, York and Kozloff 1987, Loughlin *et al.* 1992, Springer 1993). Reduced food availability might have played a role in some or all of these declines (*e.g.*, Merrick *et al.* 1987, Trites 1992, Springer 1993, Calkins *et al.* 1998, Pitcher *et al.* 1998).

In Alaska, detailed data (*e.g.*, daily counts of all seals and of pups during the pupping and molting periods) on harbor seals are collected at three land-based ‘index’ sites: Tugidak Island, Nanvak Bay, and Johns Hopkins Inlet in Glacier Bay. Counts of seals at these index sites do not provide estimates of total population size, but they do estimate population trend and provide indices of local and regional seal abundance (Pitcher 1990). However, estimates of population trend and abundance from counts are biased, because the proportion of seals in the population available to be counted is not constant. Additional information on environmental and survey-related ‘covariates’ (*e.g.*, date, time of day, tide, and weather conditions) should be incorporated into statistical analyses to account for variation in the proportion of the seal population ashore when counts are conducted (Frost *et al.* 1999, Mathews and Pendleton 2000, Daniel *et al.* 2001, Jemison *et al.* 2001, Small *et al.*

2001). Subsequently, knowledge of the effects of covariates on the proportion available to be counted can be used to improve the experimental design, data collection, and statistical analyses of spatially extensive population surveys (e.g., aerial surveys of multiple sites) resulting in more accurate and precise estimates of population trend and abundance (Adkison *et al.* 2001).

The longest time series of land-based counts of harbor seals in Alaska, dating from 1976, is from Tugidak Island. Taking into account the effects of auxiliary covariates, we update the long-term population trend estimate of Pitcher (1990) based on molting period counts through 1999. We also estimate population trends for both the pupping (pups and all seals) and molting (all seals) periods during 1994-1999. We compare these trend estimates with other estimates for Tugidak Island and the Kodiak region and with estimates from other areas. We examine seasonal and diurnal variation in counts of seals hauled out and determine the effects of weather and other variables on counts. In addition, we document dates of maximum counts during pupping and molting and discuss how detailed data from index sites relates to data from geographically extensive (aerial) surveys.

## METHODS

*Study area*---Harbor seals haul out on Southwest (SW) Beach and Middle Beach along the southern and western shores of Tugidak Island (56°30'N, 154°40'W; Fig. 1). These sand and gravel beaches are bordered by 15 – 30 meter cliffs that afford excellent views of the seals. Haulout space typically is available to seals during most tide stages although space is reduced during moderate high tides and not available during extreme high tides. Seals also haul out on the beaches and sandbars in and around the lagoon on the northeast end of the island; these sites are difficult to observe from land and are not included in this study.

*Data collection*---We used spotting scopes (20x - 60x) and binoculars (10 x 42) from atop the cliffs to conduct daily counts of total seals and pups during the pupping period in May - June and during the molting period from mid July - mid September in 1994 - 1999. We identified the pupping and molting periods based on visual observations of seal behavior and pelage condition. We counted the total number of seals ashore and the number of pups, documented dates of maximum counts, and recorded weather conditions (cloud cover, precipitation, air temperature, wind speed, and wind direction).

*Analyses*---From 1994 – 1999, similar numbers of seals used SW and Middle beaches during the pupping period and combined counts collected from both beaches were used in the analyses. During the molting period, seals primarily used SW Beach although Middle Beach was used through early to mid August and then abandoned. For the molting period analyses we combined counts from SW and Middle beaches until Middle Beach was abandoned, then we used SW Beach counts. We additionally used counts collected from SW Beach during the molting period from 1976 – 1992 (from Pitcher 1990 and ADF&G unpublished). Middle Beach was not monitored regularly during those years, and because the small numbers of seals (<50) that hauled out sporadically on Middle Beach constituted only a small fraction of the total number of seals, counts from Middle Beach collected prior to 1994 were not included.

We analyzed counts from 25 May through 20 June during pupping and from 24 July through 31 August during molting. We estimated four separate trends in harbor seal counts on Tugidak Island: pups and all seals during the 1994-1999 pupping period, and all seals during the molting

periods of 1994-1999 and 1976-1999. When estimating trends, we evaluated the influence of the following covariates on counts: date, time relative to solar noon, time in relation to low tide, tide height (interpolated from published tide tables), and weather conditions. Weather covariates included: cloud cover (none, partial, complete), precipitation (none, mist/light rain, heavy rain), air temperature ( $^{\circ}\text{C}$ ), average March sea surface temperature for each year (as a measure of oceanic conditions), wind speed (in mph), and wind direction (five categories based on predominant weather patterns: N and NE; E, SE, and S; SW; W and NW; calm or variable). We allowed the effect of wind speed to vary by wind direction category. We evaluated quadratic terms for the covariates date, time of day, time relative to low tide, tide height, and wind speed (by direction). Analysis of molting period counts from 1976-1999 included seasonal and diurnal effects but not weather covariates, except for March sea surface temperature. A quadratic year effect was included because of the longer time span. We use the 1994 – 1999 analyses to discuss the effects of covariates because the long term analysis (1976 – 1999) is not based on the complete suite of covariates and relatively few counts (10 or less per year) were available in five of the earlier years (1977, 1982 – 1988). We documented dates of maximum counts in years when long time series were available.

Many studies have shown that numbers of harbor seals hauled out vary significantly with date (Schneider and Payne 1983, Allen *et al.* 1988, Grellier *et al.* 1996, Thompson *et al.* 1997, Frost *et al.* 1999, Small *et al.* 2001). Within both the pupping and molting periods, the number of seals ashore generally increases to a peak then declines. There are several approaches to account for this pattern. One is to fit a single curve for all years of survey data (Small *et al.* 2001), which assumes that the shape and peak date of the curve are the same for all years. With this approach, non-directional variation among years in the actual timing of peak abundance does not bias estimates of trend but potentially reduces precision (Adkison *et al.* 2001). If sufficient data are available (i.e., enough counts throughout the pupping or molting period), another strategy is to align the peaks of the counts across years prior to analysis. This method assumes that only the shape of the curve, and not the peak date, are the same among years. We used this latter method for the 1994-1999 pupping period analyses (both pups and all seals), because we had long series of counts within all years to determine the date of peak abundance. Within each year, we subtracted the date of the maximum count from each date to center the data. Therefore, the date covariate represents the decrease in counts relative to the within-year peak. For both the 1994-1999 and 1976-1999 molting periods, sufficient counts were not available to estimate the date of peak abundance for each year, and thus we fit a single curve for all years.

We estimated trends and adjusted counts for effects of covariates using mixed generalized linear models (Poisson errors and log link) (Littell *et al.* 1996). We accounted for temporal autocorrelation among counts within years by using a spatial correlation structure with distance based on the time elapsed between counts (Littell *et al.* 1996). When final models did not fit the Poisson assumptions (variance > mean), we used quasilielihood methods (McCullagh and Nelder 1989) to inflate the estimated standard errors. We began with the full model including all of the covariates and quadratic terms and eliminated terms from the model one at a time based on the Wald test statistics ( $P > 0.05$ ). We also used a small sample version of Akaike's Information Criteria (AICc) to help assess which variables to retain in the final model (Hurvich and Tsai 1989). In order to estimate trend, the year effect was retained in all models regardless of the Wald statistic.

## RESULTS

*Trends*---For the 23-year period from 1976-1999, the population of harbor seals on Tugidak Island declined dramatically through the early 1980s, followed by a period of stabilization prior to a population increase beginning in the mid-1990s (Fig. 2). The overall annual trend across these periods was -6.7%. Harbor seal numbers increased at a moderate rate from 1994-1999, with annual trends of 6.7% and 4.9% for all seals counted during the pupping and molting periods, respectively (Table 1; Fig 3A, B). The number of pups increased at a substantially higher annual rate of 13.6% during the same period (Fig. 3C).

*Covariates*---Date and time of day were significant covariates in all analyses (Table 1, Fig. 4 & 5). The effect of weather variables on counts of seals was not consistent. During the pupping period, mean counts of all seals were 23% lower on clear days than on days with complete cloud cover. Counts were 22% and 12% lower during periods of heavy rain and light rain/mist, respectively, than when it wasn't raining (Table 2). Counts increased as wind speed increased (Fig. 6A), and onshore (west) winds resulted in counts 14% lower than offshore winds (Table 2). Pup counts were relatively unaffected by weather covariates with only minor reductions during heavy rain (Table 2). The only weather covariate that affected molting period counts in the 1990s was wind speed, with the number of seals decreasing with wind speeds > 15-20 mph (Fig. 6B). March sea surface temperature was a significant covariate in the 1976-1999 molting period analysis only, with more seals counted in years with higher temperatures. Tide variables and air temperature were not significant in any analysis.

*Maximal counts*---During the pupping period, the annual date of the maximum count of all seals varied considerably (30 May-15 June) (Table 3). The date of the maximum counts during the molting period were 2 – 4 weeks earlier and more stable during the 1990s (2 – 8 August) than in the 1970s (19 August – 2 September) (Table 3).

## DISCUSSION

*Tugidak Island trends*---The harbor seal population on Tugidak Island declined from 1976 through the 1980s, stabilized during the early to mid 1990s, and is now increasing (Fig. 2). Our trend estimate (6.7%/yr) for all seals during the pupping period was similar to our molting period estimate (4.9%/yr) from 1994 – 1999. The estimated annual rate of increase (13.6%) among pups, however, was more than twice our trend estimates for all seals during the pupping and molting periods. Populations of harbor seals in the northeastern Pacific have fluctuated during historic times and have been subject to a variety of natural and anthropogenic influences (e.g., Fisher 1952, Lensink 1958, Olesiuk *et al.* 1990, Pitcher 1990). Bounties and predator control programs designed to reduce seal predation on commercially important fish species led to periodically high levels of harbor seal harassment and killing along the western coast of North America from the early 1900s through the early 1970s (Fisher 1952, Lensink 1958, Pearson and Verts 1970, Newby 1973, Stewart *et al.* 1988, Paige 1993). During the 1960s and early 1970s, a lucrative commercial market for seal pelts led to heavy harvests in parts of British Columbia and Alaska, including Tugidak Island where an estimated 75 – 90% of the pup production was harvested in some years (Bishop 1967, Bigg 1969).

Protection was afforded harbor seals in 1970 in Canada and in 1972 in the United States via passage of the Marine Mammal Protection Act.

The end of exploitation led, in part, to population increases along much of the western coast of North America (Jefferies 1986, Boveng 1988, Harvey *et al.* 1990, Olesiuk *et al.* 1990). Although a similar population increase following release from high harvest pressure would have been expected at Tugidak Island (Pitcher 1990), seal populations at Tugidak Island, and elsewhere in the central and western Gulf of Alaska, declined dramatically during the late 1970s and 1980s (Pitcher 1990, Frost *et al.* 1999). Pitcher (1990) estimated molting period declines of -17%/yr from 1976-1988 with a steeper decline from 1976 - 1978 (-21%/yr) and a less catastrophic decline from 1978 - 1988 (-7%/yr). Using additional data from the 1990s, we estimated a -6.7%/yr decline for harbor seals during the molting period at Tugidak Island for the entire 1976-1999 interval. Our estimate of a slower rate of decline does not contradict the greater rates of decline of Pitcher (1990), because trend estimates are interval specific and our estimate includes a longer time span and incorporates a period of stability and increase (Fig. 2).

A similar pattern of decline and recent stability or increase has been documented at Nanvak Bay, an index site in northern Bristol Bay. In 1975, maximum counts of all seals were 2-3 times higher during pupping and 6 times higher during molting compared to maximum counts in the early 1990s. From 1990 through 2000, however, seal numbers increased 9.2%/yr during pupping and 2.1%/yr during molting (Jemison *et al.* 2001). Harbor seal populations in Prince William Sound also have declined since at least 1984, with only part of that decline potentially due to the 1989 *Exxon Valdez* oil spill (Frost *et al.* 1999).

Harbor seal populations southeast of the Gulf of Alaska along the shores of North America have shown a different pattern in recent decades. These populations did not undergo large declines in the 1970s and 1980s, but have generally increased over this period. Specifically, in southern Southeast Alaska, the harbor seal population increased an estimated 7.4% annually from 1983 - 1998, similar to increases in British Columbia (12.5%/year from 1973 - 1988), Washington (7% - 30% from 1977 - 1984), Oregon (about 8%/year from 1975 - 1983) and California (15% from 1965 - 1986) (Jefferies 1986, Boveng 1988, Harvey *et al.* 1990, Olesiuk 1990, Small *et al.* 2001). However, these increases have not been uniform across the entire coast. Population trends in north-central Southeast Alaska were 1.1%/yr from 1984 through 1999, indicating stability (Small *et al.* 2001) and declines have been documented in Glacier Bay at both terrestrial and glacial ice haulouts from 1992 - 1998 (Mathews and Pendleton 2000).

Concurrent with the patterns of change observed in harbor seal populations in the northeastern Pacific, similar population changes have been documented for Steller sea lions in Alaska, with populations declining in the western Gulf of Alaska and the Bering Sea (Merrick *et al.* 1987, Loughlin *et al.* 1992), but stable or increasing in Southeast Alaska (Calkins *et al.* 1999), suggesting these parallel trends may be influenced by some larger oceanic effect. The cause of marine mammal declines in the Gulf of Alaska and Bering Sea, but increasing trends in adjacent areas remains unclear. A leading hypothesis points to changes in prey abundance and/or availability playing a role (e.g., Merrick *et al.* 1987, Trites 1992, Merrick *et al.* 1997, Calkins *et al.* 1998, Pitcher *et al.* 1998, Jemison and Kelly 2001).

*Covariate effects*---In addition to changes in seal population abundance, other factors influence the number of seals on shore. We observed two peaks in the number of seals hauled out from May through September. The first peak coincided with the birth of pups, the second corresponded to a time when a large portion of the population was molting (Fig. 7). Seasonal fluctuations in counts

associated with pupping and molting are well documented (*e.g.*, Stewart and Yochem 1984, Allen *et al.* 1988, Grellier *et al.* 1996). On a finer scale, diurnal patterns, time of day, and weather and tidal variables can affect the number of seals hauled out. On Tugidak Island, the covariates that most consistently affected the number of seals on shore during both pupping and molting periods were date and time of day. The dates of the maximum pup counts were highly consistent during the 1990s but occurred 1-2 weeks earlier than in the late 1970s (Jemison and Kelly 2001). However, the date of peak counts of all seals during the pupping period varied among years, perhaps due to haulout behavior of juveniles and adult males that do not have strong ties to land during the pupping period.

Seals haul out more frequently and for longer periods when molting, presumably due to higher energetic demands associated with pelage regeneration (Feltz and Fay 1966, Stewart and Yochem 1984, Calambokidis *et al.* 1987, Thompson *et al.* 1989, Watts 1992, Boily 1995, Watts 1996). Dates of maximum molting period counts were similar from 1997 – 1999, occurring from 2 – 8 August. This timing, however, represents a 2-4 week shift in the maximum molting period counts obtained during the 1970s. A temporal shift in peak counts could result from changes in the sex/age structure of seals on shore and/or from a shift among all sex/age classes to an earlier molting period. Timing of molting varies among cohorts with yearlings molting first, followed by subadults, adult females, and finally adult males, and the abundance of each cohort is positively related to the active stages of molting (Daniel *et al.* 2001). The shift in date of peak counts may indicate that younger seals make up a larger portion of the population in recent years compared to several decades ago, consistent with an increasing population. There is, however, some direct evidence that at least juveniles molted earlier on Tugidak Island during the 1990s than in the 1970s (Daniel *et al.* 2001). Given earlier dates of the onset and peak of pupping (Jemison and Kelly 2001) we would expect that molting would occur earlier as well. In our estimate of population trend during the molting period, we were unable to adjust for the temporal shift in peak counts due to insufficient data. Although the shift likely results in an over estimate of the decline, the magnitude of the decline across this long interval was so large that it is unlikely to be a major source of the apparent decline.

The covariate model predicted highest counts centered around midday (approximately 12:30 – 16:30) during the molting period but 2-4 hours after midday (approximately 16:20 – 18:20) during the pupping period. Studies of harbor seals in other areas also have identified time of day as an important factor related to counts of seal, but the relationship is not consistent among areas (Stewart 1984, Pauli and Terhune 1987, Thompson *et al.* 1989, Kovacs *et al.* 1990). The haulout pattern for Nanvak Bay is similar to that of Tugidak Island with counts higher in the afternoon (Jemison *et al.* 2001). Time of day was positively related to the number of seals hauled out along the Kodiak Archipelago (Small *et al.* 2001), consistent with our findings. But, modeling the affect of time of day on Prince William Sound counts predicted 25% more seals would be hauled out 2 – 4 hours before midday (Frost *et al.* 1999). Additional analyses of the Prince William Sound data suggest that seal numbers are relatively constant in the morning then decrease throughout the day (J. Ver Hoef, AK Dept. of Fish and Game, Fairbanks, AK; personal communications, October 2000). These differences in haulout patterns highlight the importance of evaluating covariate effects among haulout sites and regions when surveying multiple sites.

We considered both tide height at the time of the survey and the time relative to the closest low tide. In studies at sites where haulout substrate is available only at low or moderate tides, maximum counts of seals have been reported during morning low tides (Olesiuk *et al.* 1990) and more frequently during afternoon low tides (Allen *et al.* 1984, Pauli and Terhune 1987, Thompson *et al.* 1989, Kovacs *et al.* 1990, Watts 1996). In other studies at sites where haulout space is available during all tidal stages, diurnal patterns dominant over tidal cycles with seal numbers peaking in the

afternoon (Stewart 1984, Godsell 1988). Our results agree with this second set of studies. We found strong diurnal effects but no relationship between tide variables and seal counts in any of our analyses. At Tugidak Island, haulout substrate is reduced but still available during high tides and typically seals can haul out on all but extreme high tides or moderate tides with strong on-shore winds.

We also investigated the effect of weather variables including precipitation, cloud cover, wind speed and direction, and both air temperature at the time of the count and March sea surface temperature. Pup counts had a weak relationship with precipitation, but their haulout patterns were unaffected by other weather conditions. This suggests that their need to haul out might be greater than that of other age classes of seals and that they will haul out under most conditions. Total counts during the molting period also were relatively unaffected by weather other than a decline in counts with high winds, again suggesting the importance of hauling out during this period. In contrast, total counts of seals during the pupping period showed changes of up to 25% in relation to precipitation and cloud cover. In addition, counts declined with onshore winds but increased with wind speed; the cause of this later relationship is unclear. The greater influence of weather factors and the variation in the date of peak counts (of all seals) during the pupping period suggest that seals (probably excluding mother-pup pairs) are more likely to haul out under optimal weather conditions. Other studies have found environmental conditions such as precipitation, wind speed, wave action, and air temperature affect harbor seal haulout behavior at some locations (Schneider and Payne 1983, Kreiber and Barrette 1984, Watts 1992, Grellier *et al.* 1996), however the effects are not always consistent among sites and years. March sea surface temperature was a significant covariate in the 1976-1999 molting period analysis, with more seals counted in years with higher temperatures (after adjusting for abundance). Sea surface temperature did not change in a consistent pattern across years of the study, but was lowest in the early 1970s and late 1990s and highest in the late 1970s through the mid 1980s. Weather conditions may be less important in design of harbor seal studies using pupping and molting period counts but could be included in the analysis of the counts.

*Land-based vs. aerial surveys*---In addition to index sites, such as Tugidak Island and Nanvak Bay, harbor seal populations in Alaska have been regularly monitored during the 1980s and 1990s along five aerial survey routes. These survey routes, each consisting of 16 to 30 individual haulouts, generally are surveyed six to ten times annually between mid-August and early September. Intensive studies at index sites have been proposed as aids in designing geographically extensive surveys and interpreting results obtained from them. The SW and Middle beach haulouts on Tugidak Island are part of the Kodiak aerial survey route and make up a large part (40% – 45%) the route's total seal count.

Trends for the five survey routes are estimated using methods similar to our analyses, differing in having multiple sites with fewer counts per year and not considering weather covariates (Frost *et al.* 1999, Mathews and Pendleton 2000, Small *et al.* 2001). Our trend estimate for Tugidak Island (4.9%/yr; 95%CI 1.7% to 8.3%) is similar to that of the entire 1993-1999 Kodiak aerial survey (5.7%/yr; 95% CI: 3.8% to 7.6%) (Small *et al.* 2001), but quite different from the estimate based on Tugidak Island aerial data only (1.4%; 95% CI: -4.1% to 6.8%) (G. Pendleton unpublished). And, because of the smaller amount of data from the Tugidak aerial counts, the confidence interval is much larger.

One possible reason for the discrepancy between the two estimates of population trend for Tugidak Island is the effect of the covariate adjustments. Because the aerial survey has fewer data points per site collected over narrower ranges of the covariates, the covariate effects from the single

site data might be poorly estimated, resulting in poor estimates of trend as well. In the analysis of data from the entire Kodiak survey route, all covariates except tide were assumed to act equally at all sites thus allowing more data to estimate each effect. Based on our land-based counts from Tugidak Island, we found maximum numbers hauled out in early August. Date covariates for both Tugidak only and the Kodiak route predict peak counts prior to the earliest dates of the aerial survey in mid-August (G. Pendleton, unpublished) and thus agree with the analysis of the land-based data. Similarly, both aerial survey results (Tugidak only and entire Kodiak survey route) predict the highest counts in the afternoon after midday, somewhat later than what we found with the land-based counts (peak centered around midday) but generally consistent. One discrepancy between the land-based and aerial covariate estimates concerns effects of tide. Both aerial survey analyses indicated that counts from Tugidak Island increased with tide height, whereas we found no tide effect on land-based counts. Possible confounding between tide height and time of day (higher tides generally occurring in the afternoon at this time of year, S. Crowley, AK Dept. of Fish and Game, Juneau, AK; personal communications, November 2000), which was not a problem with the more data-rich land-based counts, might be the source of this relationship. Wind also affected land-based counts, but was not included in the analyses of aerial survey data and so wind effects were not accounted for in aerial trend estimates. In general, the covariate patterns are quite consistent between the analysis of land-based and aerial count data. Sensitivity analyses and variable importance indices (Burnham and Anderson 1998) both indicate that the covariates have little effect on the trend estimate for the Tugidak only aerial survey analyses (G. Pendleton, unpublished). Consequently, we feel that the covariate adjustments are not the source of the discrepancy between the trend estimates for Tugidak Island.

A second possibility in accounting for the difference between the land-based and aerial trend estimates for Tugidak Island is that the aerial survey is conducted under suboptimal conditions. Comparing the unadjusted mean counts from the land-based and aerial surveys suggest that this might be the case (Fig. 8). The design of the Kodiak aerial survey was based on land counts at Tugidak Island in the 1970s (Pitcher 1990) and investigations of harbor seals elsewhere (e.g., Prince William Sound). Optimal counting conditions at Tugidak Island might have changed or are different than those at other locations. The timing of the molting period peak count at Tugidak is several weeks earlier now than it was in the 1970s. In recent years the Kodiak aerial survey has been conducted to coincide with the lowest tide cycles of the molting period. These lowest tides often occur before midday. In Prince William Sound, harbor seal counts are highest in the morning and tide has a major influence on haulout patterns at some sites. (Frost *et al.* 1999). There is strong evidence that the effect of tide on counts varies among sites within the Kodiak aerial survey route (Small *et al.* 2001). Inclusion of covariates in the analysis models can overcome some of these design problems, but often not all, especially when data from only a single site is analyzed. It is probably not possible to design a multi-site survey to accommodate all site-specific differences in the true effects of external factors. But considering an entire survey route, survey conditions likely are more optimal on the average than for individual sites. This factor along with combined analyses of entire route data using larger sample sizes and better estimates of covariate effects seems to overcome the problem of varying site effects to some extent.

Locations where land-based studies of harbor seal haulout patterns can be conducted are rare in Alaska, and the features that make study possible at these sites (e.g., larger topographic relief) also might make them less representative of some other haulout sites. Important information can be obtained from land-based index sites, including timing of life history events and temporal shifts in those events, factors that affect haulout behavior, and estimates of population trend (Daniel *et al.*

2001, Jemison and Kelly 2001). The insights obtained from detailed land-based studies are valuable for interpreting and designing geographically extensive surveys, but caution is needed in applying results from these studies to structurally different sites.

#### ACKNOWLEDGEMENTS

We are grateful to the people who assisted with counts of harbor seals on Tugidak Island: J. Donnel, M. Edens, O. Harding, J. Kafka, L. Milette, G. Sheffield, M. Simpkins, C. Wilson and especially S. Crowley and R. Daniel. Unpublished data were provided by B. Johnson, P. Johnson, B. Kelly, D. McAllister, and the Alaska Department of Fish and Game. Valuable logistical support was provided by J. & M. Garber, D. Prokopowich, and K. Wynne. We thank B. Kelly for valuable advice on this project. Comments from R. Small and K. Hastings greatly improved the quality of this report. We are especially grateful to K. Pitcher and the late F. Fay who were instrumental in beginning counts at Tugidak Island during the 1970s. The Alaska Department of Fish and Game and the University of Alaska Fairbanks provided funding for this project.

#### LITERATURE CITED

- Allen, S. G., D. G. Ainley, G. W. Page and C. A. Ribic. 1984. The effect of disturbance on harbor seal haulout patterns at Bolinas Lagoon, California. *Fishery Bulletin* 82:493-500.
- Allen, S. G., C. A. Ribic and J. E. Kjelmyr. 1988. Herd segregation in harbor seals at Point Reyes, California. *California Fish and Game* 74:55-59.
- Adkison, M. D., T. J. Quinn, and R. J. Small. 2001. Evaluation of Alaska harbor seal (*Phoca vitulina*) population surveys: A simulation study. Pages 88-127 (this volume) *in*: Harbor Seal Investigations in Alaska. Annual Report for NOAA Award NA87FX0300. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, AK. 356 pp.
- Bigg, M. A. 1969. The harbour seal in British Columbia. *Bulletin of Fisheries Research Board of Canada*. No. 172. 33pp.
- Bishop, R. H. 1967. Reproduction, age determination, and behavior of the harbor seal, *Phoca vitulina* L., in the Gulf of Alaska. M.S. Thesis. University of Alaska, College. 121pp.
- Boily, P. 1995. Theoretical heat flux in water and habitat selection of Phocid seals and beluga whales during the annual molt. *Journal of Theoretical Biology* 172: 235-244.
- Boveng, P. 1988. Status of the Pacific harbor seal population on the U. S. west coast. National Marine Fisheries Service Administrative Report LJ-88-07. 43pp.
- Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer, New York, NY. 353pp.

- Braham, H. W., R. D. Everitt, and D. J. Rugh. 1980. Northern sea lion population decline in the Eastern Aleutian Islands. *Journal of Wildlife Management* 44:25-33.
- Calambokidis, J., B. Taylor, S. Carter, G. Steiger, P. Dawson, and L. Antrim. 1987. Distribution and haul out behavior of harbor seals in Glacier Bay, Alaska. *Canadian Journal of Zoology* 65:1391-1396.
- Calkins, D. G., E. F. Becker and K. W. Pitcher. 1998. Reduced body size of female Steller sea lions from a declining population in the Gulf of Alaska. *Marine Mammal Science* 14:232-244.
- Calkins, D., D. C. McAllister, K. W. Pitcher, and G. W. Pendleton. 1999. Steller sea lion status and trend in Southeast Alaska: 1979-1997. *Marine Mammal Science* 15:462-477.
- Daniel, R., L. A. Jemison, S. M. Crowley and G. W. Pendleton. 2001. Molting phenology of harbor seals on Tugidak Island, Alaska. Pages 130-145 (this volume) *in*: Harbor Seal Investigations in Alaska. Annual Report for NOAA Award NA87FX0300. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, AK. 356 pp.
- Feltz, E. T. and F. H. Fay. 1996. Thermal requirements in vitro of epidermal cells from seals. *Cryobiology* 3: 261-264.
- Fisher, H. D. 1952. The status of the harbour seal in British Columbia, with particular reference to the Skeena River. Fisheries Resources Board Canadian Bulletin. 93. 58pp.
- Fowler, C. W. 1982. Interactions of northern fur seals and commercial fisheries. *Transactions of the North American Wildlife Conference* 47:278-292.
- Frost, K. J., L. F. Lowry, and J. M. Ver Hoef. 1999. Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. *Marine Mammal Science* 15:494-506.
- Godsell, J. 1988. Herd formation and haul-out behaviour in harbour seals (*Phoca vitulina*). *Journal of Zoology, London* 215:83-98.
- Grellier, K., P. M. Thompson and H. M. Corpe. 1996. The effect of weather conditions on harbour seal (*Phoca vitulina*) haulout behaviour in the Moray Firth, northeast Scotland. *Canadian Journal of Zoology* 74:1806-1811.
- Harvey, J. T., R. F. Brown and B. R. Mate. 1990. Abundance and distribution of harbor seals (*Phoca vitulina*) in Oregon, 1975-1983. *Northwest Naturalist* 71:65-71.
- Hurvich, C. M., and C.-L. Tsai. 1989. Regression and time series model selection in small samples. *Biometrika* 76:297-307.

- Jefferies, S. J. 1986. Seasonal movements and population trends of the harbor seal (*Phoca vitulina richardsi*) in the Columbia River and adjacent waters of Washington and Oregon: 1976-82. Final Report to the Marine Mammal Commission, No. MM2079357-5. 41pp.
- Jemison, L. A. and B. P. Kelly. 2001. Pupping phenology and demography of harbor seals on Tugidak Island, Alaska. *Marine Mammal Science* *In press*.
- Jemison, L. A., G. W. Pendleton, and C. A. Wilson. 2001. Harbor seal population trends and factors influencing counts at Nanvak Bay, northern Bristol Bay, Alaska. Pages 53-70 (this volume) *in: Harbor Seal Investigations in Alaska. Annual Report for NOAA Award NA87FX0300. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, AK. 356 pp.*
- Kovacs, K., K. Jonas and S. Welke. 1990. Sex and age segregation by *Phoca vitulina concolor* at haul-out sites during the breeding season in the Passamaquoddy Bay Region, New Brunswick. *Marine Mammal Science* 6:204-214.
- Kreiber, M., and C. Barrette. 1984. Aggregation behaviour of harbour seals at Forillon National Park, Canada. *Journal of Animal Ecology* 53:913-928.
- Lensink, C. J. 1958. Predator investigation and control. Alaska Dept. Fish and Game Annual Report. Report No. 10. Juneau, Alaska. Pp 91-104.
- Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. *SAS system for mixed models*. SAS Institute, Cary, NC. 633pp.
- Loughlin, T. R., A. S. Perlov, and V. A. Vladimirov. 1992. Range-wide survey and estimation of Total number of Steller sea lions in 1989. *Marine Mammal Science* 8:220-239.
- Mathews, E. A., and G. W. Pendleton. 2000. Declining trends in harbor seal (*Phoca vitulina richardsi*) numbers at glacial ice and terrestrial haulouts in Glacier Bay National Park, 1992-1998. 24pp. Available from Glacier Bay National Park, P.O. Box 140, Gustavus, AK 99826.
- Mathisen, O. A., and R. J. Lopp. 1963. Photographic census of the Steller sea lion herds in Alaska, 1956-1958. U.S. Department of the Interior, Fish and Wildlife Service, Special Scientific Report Fish. No. 424. 20 pp. Appendix: Notes on distribution and abundance of harbor seals, *Phoca vitulina*, in the Gulf of Alaska and Aleutian Islands area. Pp 18-20.
- McCullagh, P., and J. A. Nelder. 1989. *Generalized linear models*. 2<sup>nd</sup> ed. Chapman and Hall, New York, NY.
- Merrick, R. L., T. R. Loughlin, and D. G. Calkins. 1987. Decline in abundance of northern sea lions, *Eumetopias jubatus*, in Alaska, 1956-86. *Fishery Bulletin* 85:351-365.

- Merrick, R. L., M. K. Chumbley, and G. V. Byrd. 1997. Diet diversity of Steller sea lions (*Eumetopias jubatus*) and their population decline in Alaska: a potential relationship. *Canadian Journal of Fisheries and Aquatic Science* 54:1342-1348.
- Newby, T. C. 1973. Changes in the Washington State harbor seal population, 1942 – 1972. *Murrelet* 54:4-6.
- Olesiuk, P., M. Bigg and G. Ellis. 1990. Recent trends in the abundance of harbour seals, *Phoca vitulina*, in British Columbia. *Canadian Journal of Fisheries and Aquatic Science* 47:992-1003.
- Paige, A. W. 1993. History of hair seal bounty and predator control programs in Alaska. Pages D1-D6 in R. J. Wolfe, C. Mishler, C. J. Utermohle, S. Carpenter, A. W. Paige and K. Thomas, eds. The subsistence harvest of harbor seal and sea lion by Alaska Natives in 1992. Final report for year one. Subsistence study and monitor system (No. 50ABNF200055) prepared for the National Marine Fisheries Service by the Division of Subsistence, Alaska Dept. Fish and Game, Juneau.
- Pauli, B. P. and J. M. Terhune. 1987. Tidal and temporal interactions on harbour seal haul-out patterns. *Aquatic Mammals* 13:93-95.
- Pearson, J. P., and B. J. Verts. 1970. Abundance and distribution of harbor seals and northern sea lions in Oregon. *Murrelet* 51:1-5.
- Pitcher, K. W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. *Marine Mammal Science* 6:121-134.
- Pitcher, K. W., D. C. Calkins, and G. W. Pendleton. 1998. Reproductive performances of female Steller sea lions: an energetics-based reproductive strategy? *Canadian Journal of Zoology* 76:2075-2083.
- Schneider, C. C., and P. M. Payne. 1983. Factors affecting haul-out of harbor seals at a site in southeastern Massachusetts. *Journal of Mammalogy*. 64:518-520.
- Small, R. J., G. W. Pendleton, and K. M. Wynne. 2001. Harbor seal population trends in the Ketchikan, Sitka, and Kodiak areas of Alaska, 1983-1999. Pages 8-30 (this volume) in: Harbor Seal Investigations in Alaska. Annual Report for NOAA Award NA87FX0300. Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage, AK. 356 pp.
- Springer, A. M. 1993. Report of the seabird working group. Pages 14-29 in S. Keller, ed. Is it food? Addressing marine mammal and seabird declines (workshop summary). University of Alaska, Alaska Sea Grant Report 93-01, Fairbanks, AK. 59pp.

- Stewart, B. S. 1984. Diurnal hauling patterns of harbor seals at San Miguel Island, California. *Journal of Wildlife Management* 48:1459-1461.
- Stewart, B. S., and P. K. Yochem. 1984. Seasonal abundance of pinnipeds at San Nicholas Island, California, 1980-1982. *Bulletin Southern California Academy of Sciences* 83:121-132.
- Stewart, B. S., G. A. Antonelis, R. L. Delong, and P. K. Yochem. 1988. Abundance of harbor seals on San Miguel Island, California, 1927 through 1986. *Bulletin of Southern California Academy of Sciences*. 87:39-43.
- Thompson, P. M., M. A. Fedak, B. J. McConnell AND K. S. Nicholas. 1989. Seasonal and sex related variation in the activity patterns of common seals (*Phoca vitulina*). *Journal of Applied Ecology* 26: 521-535.
- Thompson, P. M., D. J. Tollit, D. Wood, H. Corpe, P. Hammond and A. MacKay. 1997. Estimating harbour seal abundance and status in an estuarine habitat in north-east Scotland. *Journal of Applied Ecology* 34:43-52.
- Trites, A. W. 1992. Northern fur seals: why have they declined? *Aquatic Mammals* 18:3-18.
- Watts, P. 1992. Thermal constraints on hauling out by harbour seals (*Phoca vitulina*). *Canadian Journal of Zoology* 70: 553-650.
- Watts, P. 1996. The diel-hauling out cycle of harbour seals in an open marine environment: correlates and constraints. *Journal of Zoology, London* 240:1-26
- York, A. E., and P. Kozloff. 1987. On the estimation of numbers of northern fur seal, *Callorhinus ursinus*, pups born on St. Paul Island, 1980-86. *Fishery Bulletin* 85:367-375.

Table 1. Annual trend estimates for harbor seals on Tugidak Island, Alaska, during the pupping and molting periods, and covariates that significantly ( $P < 0.05$ ) influenced the number of seals hauled out. A '+' indicates a positive relationship between count and covariate and a '-' indicates a negative relationship.

Years	Season	Trend (%/yr)	95% CI	Covariates									
				Date	Date <sup>2</sup>	Time to midday	Time to midday <sup>2</sup>	Sea Surface Temp.	Cloud cover	Precip- itation	Wind speed	Wind speed <sup>2</sup>	Wind direction
1976-99 <sup>a</sup>	Molting (all seals)	-6.7% <sup>b</sup>	-7.3% to -6.1%	+	-	+	-	*					
1994-99	Molting (all seals)	4.9%	1.7% to 8.3%	-	-		-				+	-	
1994-99 <sup>b</sup>	Pupping (all seals)	6.7%	2.5% to 10.8%	+	-	+	-		*	*	+		*
1994-99 <sup>c</sup>	Pupping (pups)	13.6%	4.0% to 24.0%	+	-	+				*			

<sup>a</sup>Year<sup>2</sup> included in the model but cloud cover, precipitation, temperature, and wind variables were not available to be included.

<sup>b</sup>Wind direction reduced to 2 categories: east and west.

<sup>c</sup>Precipitation reduced to 2 categories: none or light rain, and heavy rain.

Table 2. Mean seal counts from 1994 – 1999 (and % change from the maximum) for levels of categorical weather covariates adjusted for other variables in the models.

Variable	Level	Mean Total Count (pupping period)	Mean Pup Count (pupping period)
Precipitation (rain)	none	728	163
	light	641 (-12%)	163
	heavy	569 (-22%)	150 (-4%)
Cloud Cover	none	543 (-23%)	
	partial	697 (-1%)	
	complete	701	
Wind Direction	east	692	
	west	597 (-14%)	

Table 3. Date of the maximum counts of pups and all seals on Tugidak Island, Alaska, 1976 – 1979 and 1994 – 1999.

Year	Date of maximum count during pupping (all seals)	Date of maximum pup count <sup>a</sup>	Date of maximum count during molting (all seals)
1976	22 June	22 June	31 August
1978		22-25 June	3 September
1979		≥20 June	19 August
1994	7 June	11 June	
1995	8 June	11 June	
1996	30 May	12 June	
1997	7 June	11 June	6 August
1998	12 June	11 June	2 August
1999	15 June	15 June <sup>b</sup>	8 August

<sup>a</sup>Jemison and Kelly 2001

<sup>b</sup>This study

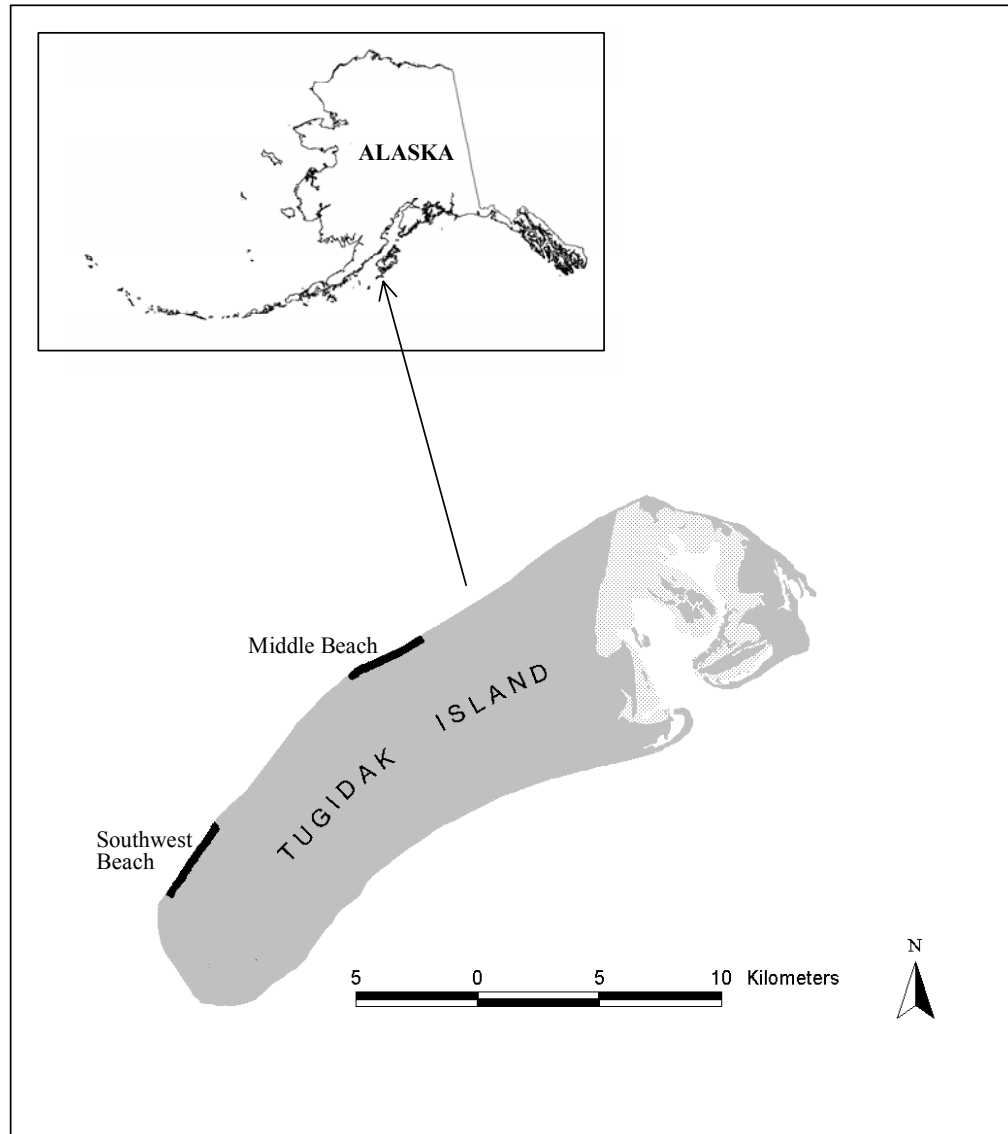


Figure 1. Location of harbor seal population monitoring sites on Tugidak Island, Alaska.

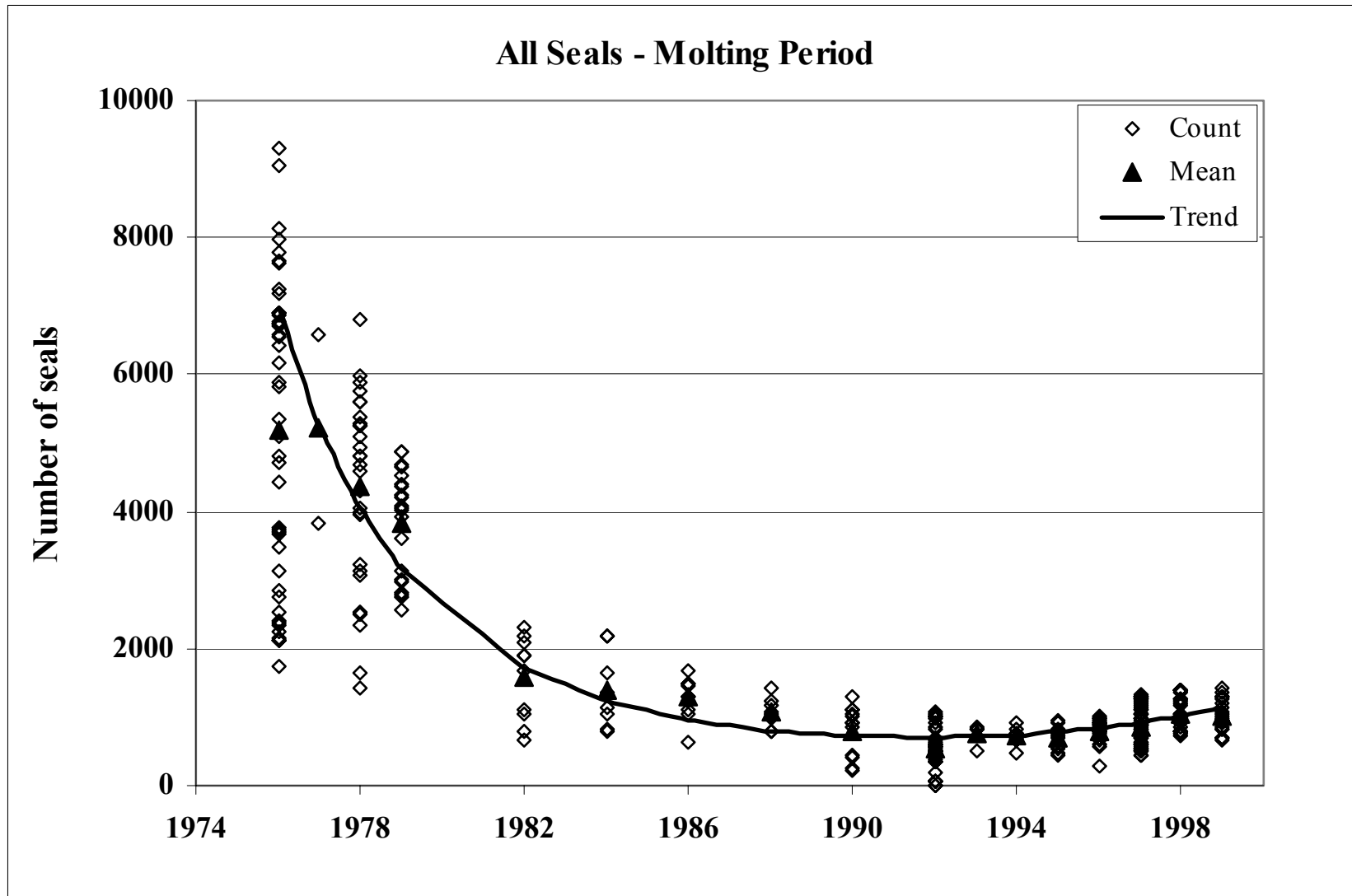


Figure 2. Estimated population trend of harbor seals on Tugidak Island, Alaska, 1976 – 1999, based on counts of all seals during the molting period. Note steep decline in the late 1970s and early 1980s and modest increase in the late 1990s.

# POPULATION TREND

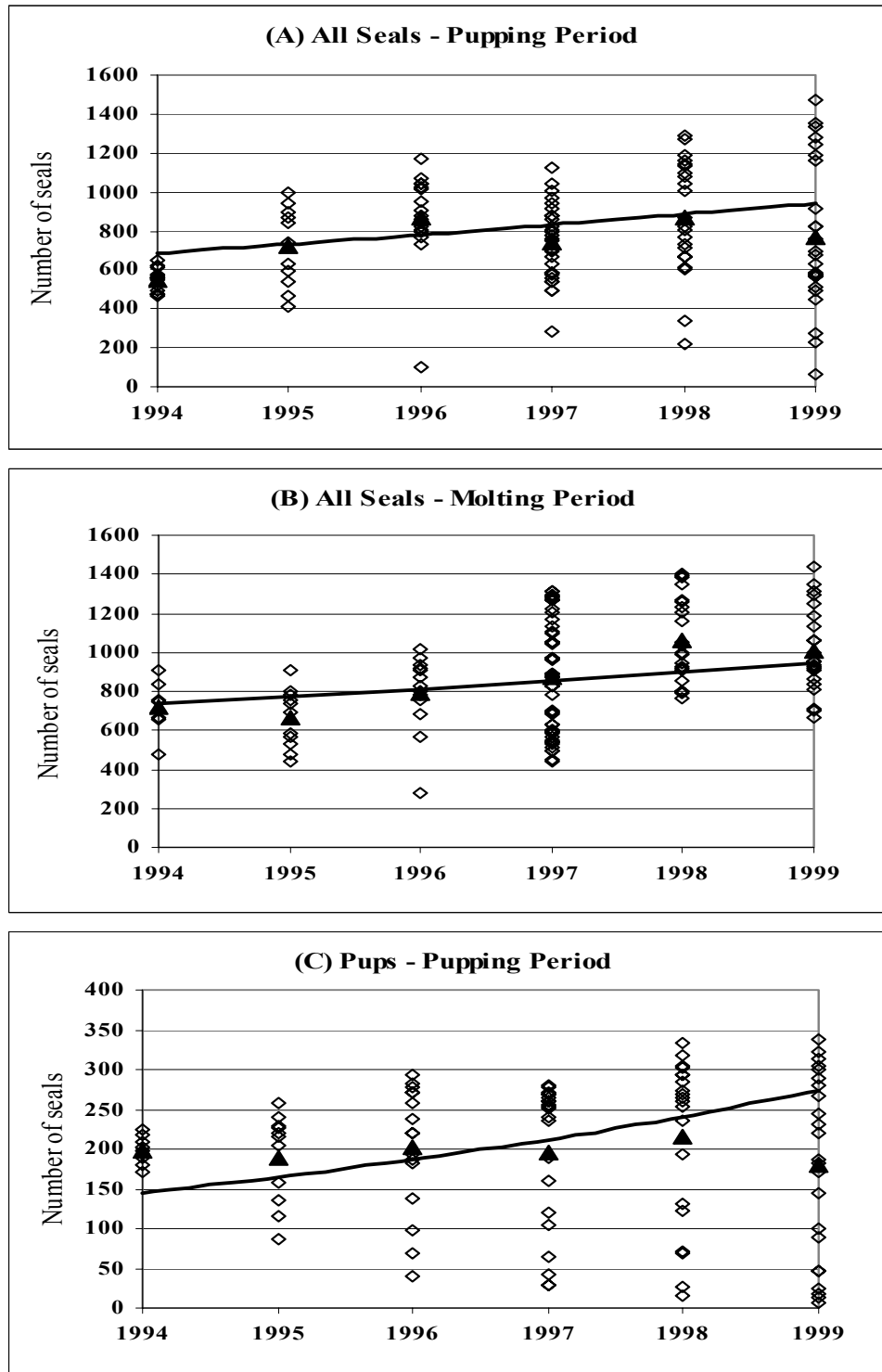


Figure 3. Estimated population trend (solid line) in harbor seals on Tugidak Island, Alaska, 1994–1999, based on counts (open diamonds) of (A) all seals during the pupping period, (B) all seals during the molting period, and (C) pups during the pupping period. Solid triangles represent mean annual count.

# COUNTS VS. DATE

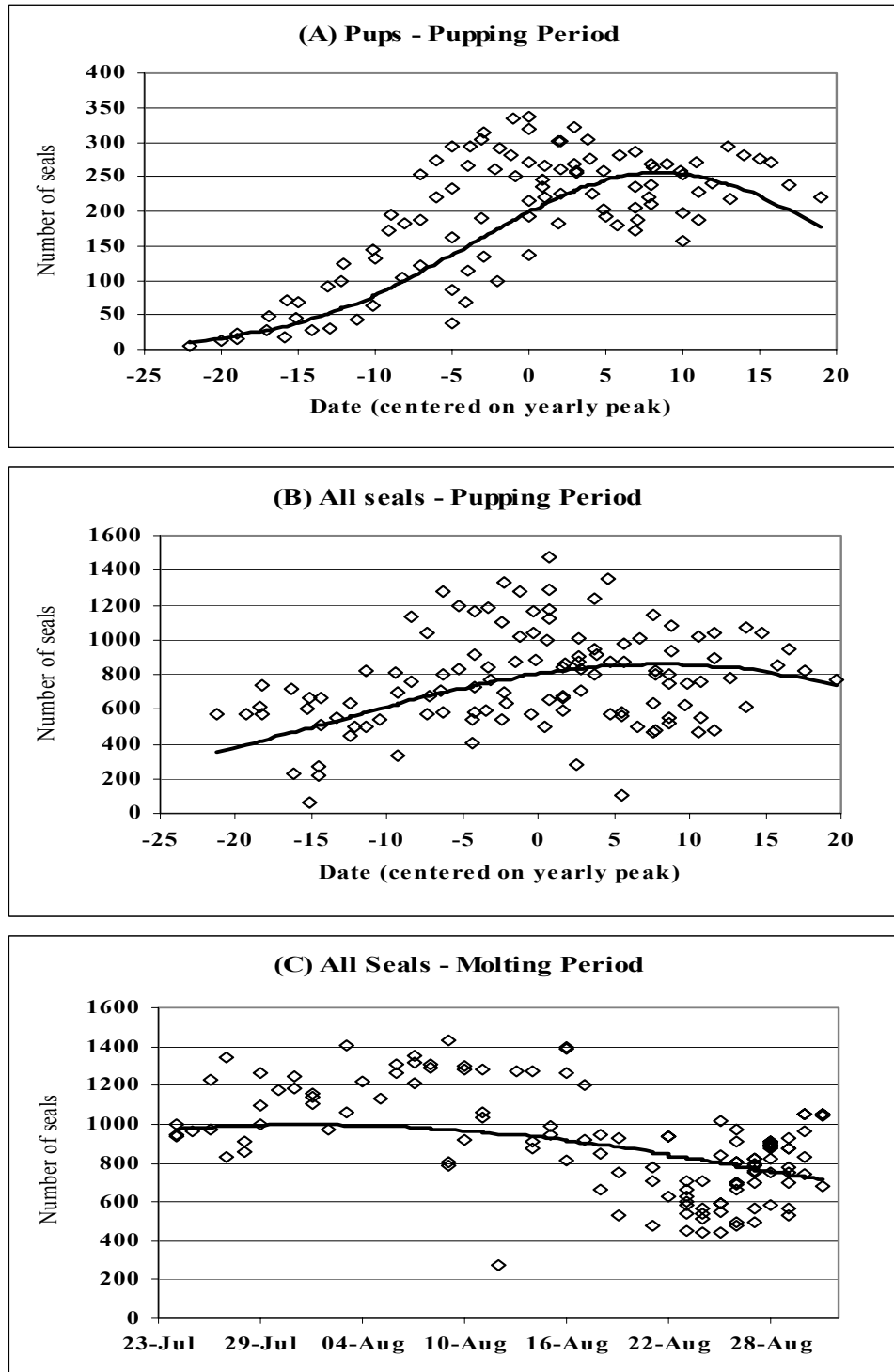


Figure 4. Predicted relationship (solid line) between date and counts (open diamonds) of (A) pups during the pupping period, (B) all seals during the pupping period, and (C) all seals during the molting period on Tugidak Island, Alaska, 1994–1999. Within each year for (A) and (B), all counts were first centered to the date of the maximum count.

## COUNTS VS. TIME OF DAY

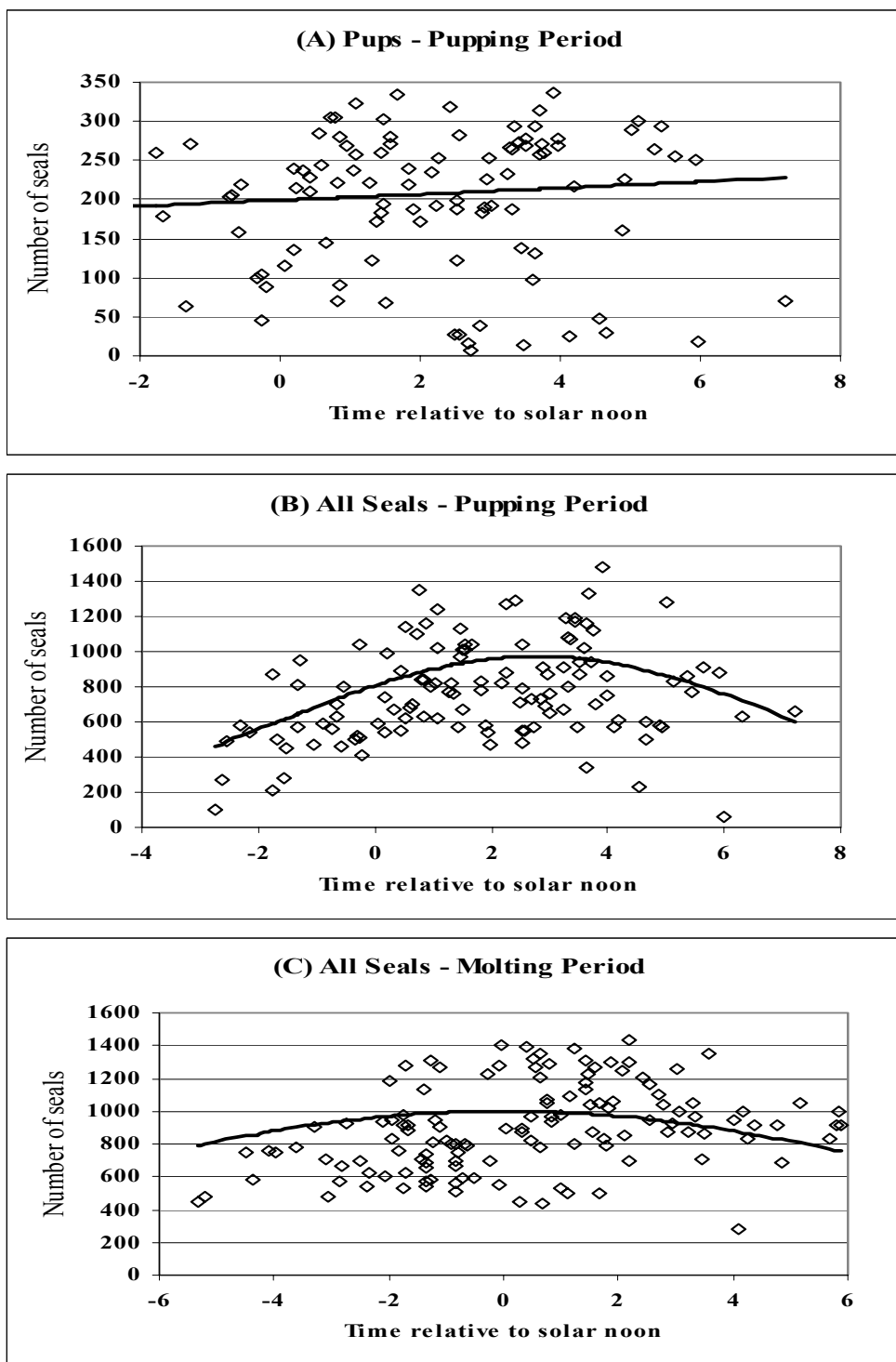


Figure 5. Predicted relationship (solid line) between time of day and counts (open diamonds) of (A) pups during the pupping period, (B) all seals during the pupping period, and (C) all seals during the molting period on Tugidak Island, Alaska, 1994–1999. The x-axis represents time relative to solar noon, which was 14:18 hrs on 5 June during the pupping period and 14:24 hrs on 5 August during the molting period.

## COUNTS VS. WIND SPEED

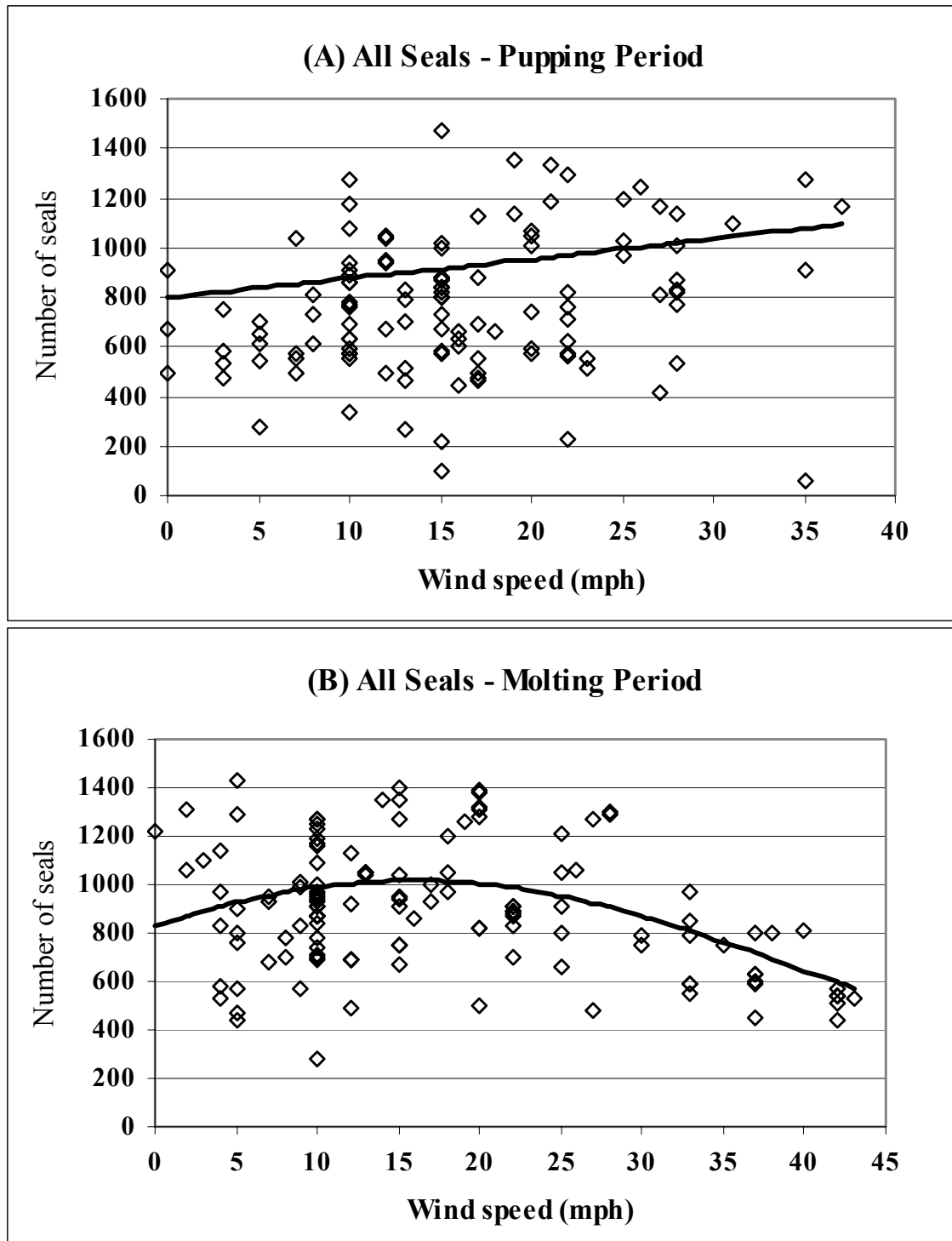


Figure 6. Predicted relationship (solid line) between wind speed and counts (open diamonds) of (A) all seals during the pupping period and (B) all seals during the molting period on Tugidak Island, Alaska, 1994–1999.

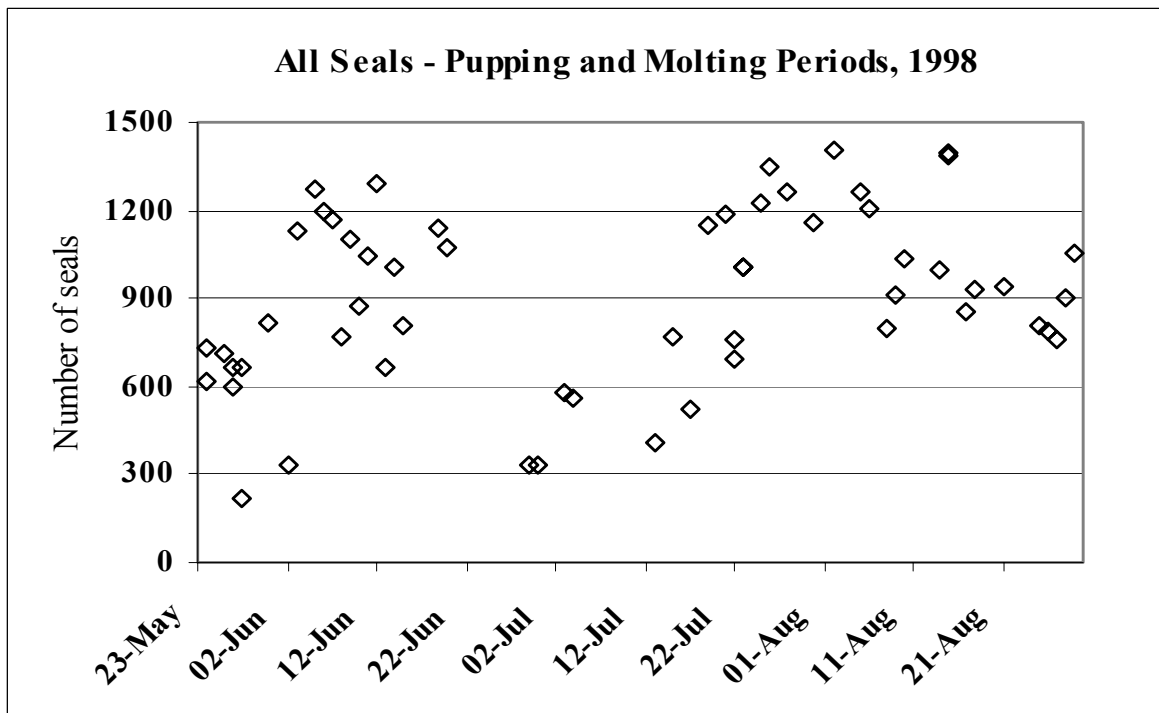


Figure 7. Counts of harbor seals during the pupping and molting periods on Tugidak Island, Alaska, 1998.

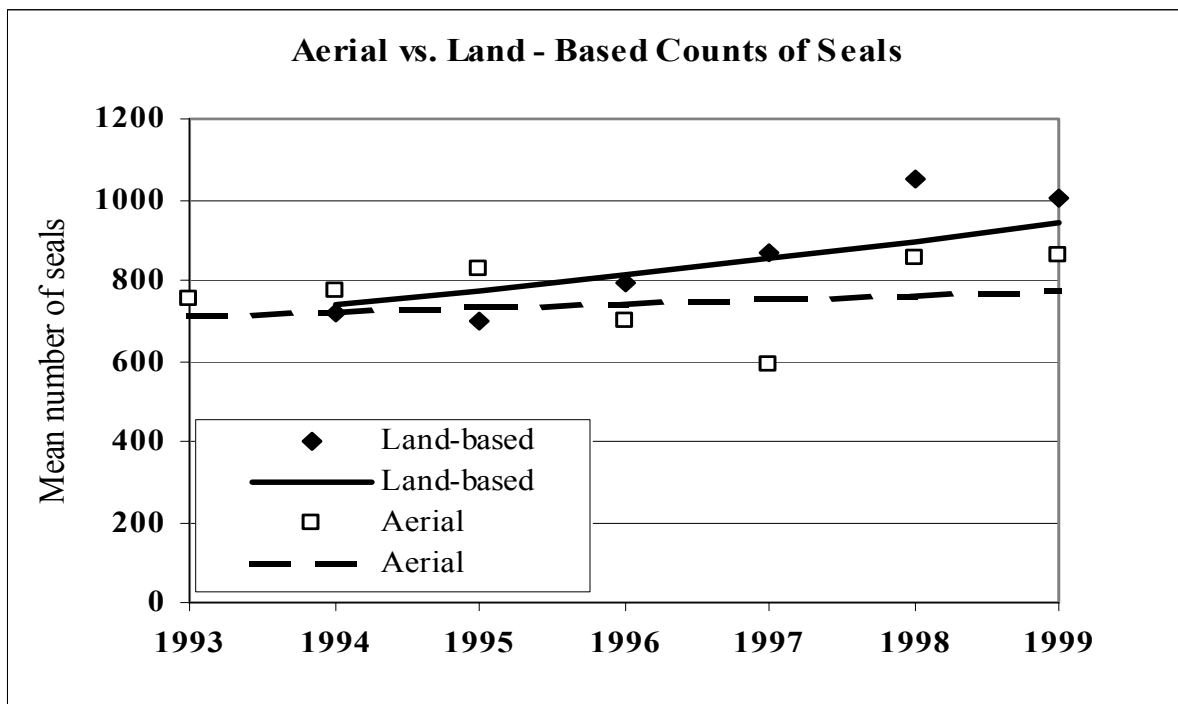


Figure 8. Mean annual counts of harbor seals during the molting period on Tugidak Island, Alaska, 1993–1999, based on aerial counts (open squares and dashed line) and land-based counts (solid diamond and solid line).